Imaging conducting domain wall dynamics at the atomic scale

Conroy, M.[1,2], Gregg, M.[3], Gruverman, A.[4] and Bangert, U.[2]

[1] Pacific Northwest National Laboratory, Ireland, [2] TEMUL, Department of Physics, School of Natural Sciences & Bernal Institute, University of Limerick, Ireland, [3] Department of Physics and Mathematics, Queens University, Belfast, United Kingdom, [4] Department of Physics and Astronomy, University of Nebraska, Lincoln, United States

Conducting domain wall ferroelectrics is an emerging research focus in nano-electronics.[1-2] The previously overlooked domain walls have recently been reported to possess diverse functional characteristics that are completely different from the domains that they delineate.[3-5] They have their own distinct chemistry and magnetic behavior[6] and in turn representing a completely new conducting sheet phase. The characteristics of these confined regions are believed to have the same exotic functional behaviors as seen in established 2D materials such as graphene, opening up a plethora of possible electronic applications. In addition the walls have the unique property of being 'agile'; they can be created or destroyed and even by controllably moved by an external electric field. However this is an area of research at its very early stages with a great deal of the fundamental physics unknown. With the region of interest atomically thin and dynamic it is essential for the physical characterization to be at this scale and time resolved.

In this study we investigate the 2D domain wall atomic arrangement of $(Pb,Sr)TiO_3$ crystals using high resolution transmission electron microscopy. It is vital to visualize and interpret the displacement of atoms and thus molecular dipole at these boundaries with changing domain polarization so we can in future control the potential device ferroelectrics. Additionally we studied the chemical nature and its variation along the boundary by high angle annular dark field in scanning mode with complimentary atomic resolution energy dispersive x-ray and electron energy loss spectroscopy. To study the dynamic nature of these 2D sheets we utilized the electron beam probe itself to not only image, but also to write/create the domain walls providing valuable *in-situ* insights into the fundamental processes of defect formation and charge carrier behavior. Finally we examined with an *in-situ* biasing microscope stage the effect of an applied electric field to the atomic arrangement of the 2D region, while simultaneously investigating the electron beam induced currents produced by the probe.

This research is being funded by the Irish Research Council.

Bibliography:

1. McQuaid, R. G. P.; Campbell, M. P.; Whatmore, R. W.; Kumar, A.; Gregg, J. M., Injection and controlled motion of conducting domain walls in improper ferroelectric Cu-Cl boracite. *Nature Communications* **2017,** *8*, 15105.
2. Jiang, J.; Bai, Z. L.; Chen, Z. H.; He, L.; Zhang, D. W.; Zhang, Q. H.; Shi, J. A.; Park, M. H.; Scott, J. F.; Hwang, C. S.; Jiang, A. Q., Temporary formation of highly conducting domain walls for non-destructive read-out of ferroelectric domain-wall resistance switching memories. *Nature Materials* **2017,** *17*, 49.
3. McGilly, L. J.; Yudin, P.; Feigl, L.; Tagantsev, A. K.; Setter, N., Controlling domain wall motion in ferroelectric thin films. *Nature Nanotechnology* **2015,** *10*, 145.
4. Seidel, J., Domain Walls as Nanoscale Functional Elements. *The Journal of Physical Chemistry Letters* **2012,** *3* (19), 2905-2909.
5. Catalan, G.; Seidel, J.; Ramesh, R.; Scott, J. F., Domain wall nanoelectronics. *Reviews of Modern Physics* **2012,** *84* (1), 119-156.
6. Farokhipoor, S.; Magén, C.; Venkatesan, S.; Íæ#177;iguez, J.; Daumont, C. J. M.; Rubi, D.; Snoeck, E.; Mostovoy, M.; de Graaf, C.; Müller, A.; Döblinger, M.; Scheu, C.; Noheda, B., Artificial chemical and magnetic structure at the domain walls of an epitaxial oxide. *Nature* **2014,** *515*, 379.